Wakulla Springs – Woodville Karst Plain Research Update

by
Timothy J. Hazlett, Ph.D.
Hazlett-Kincaid, Inc.
www.hazlett-kincaid.com/FGS

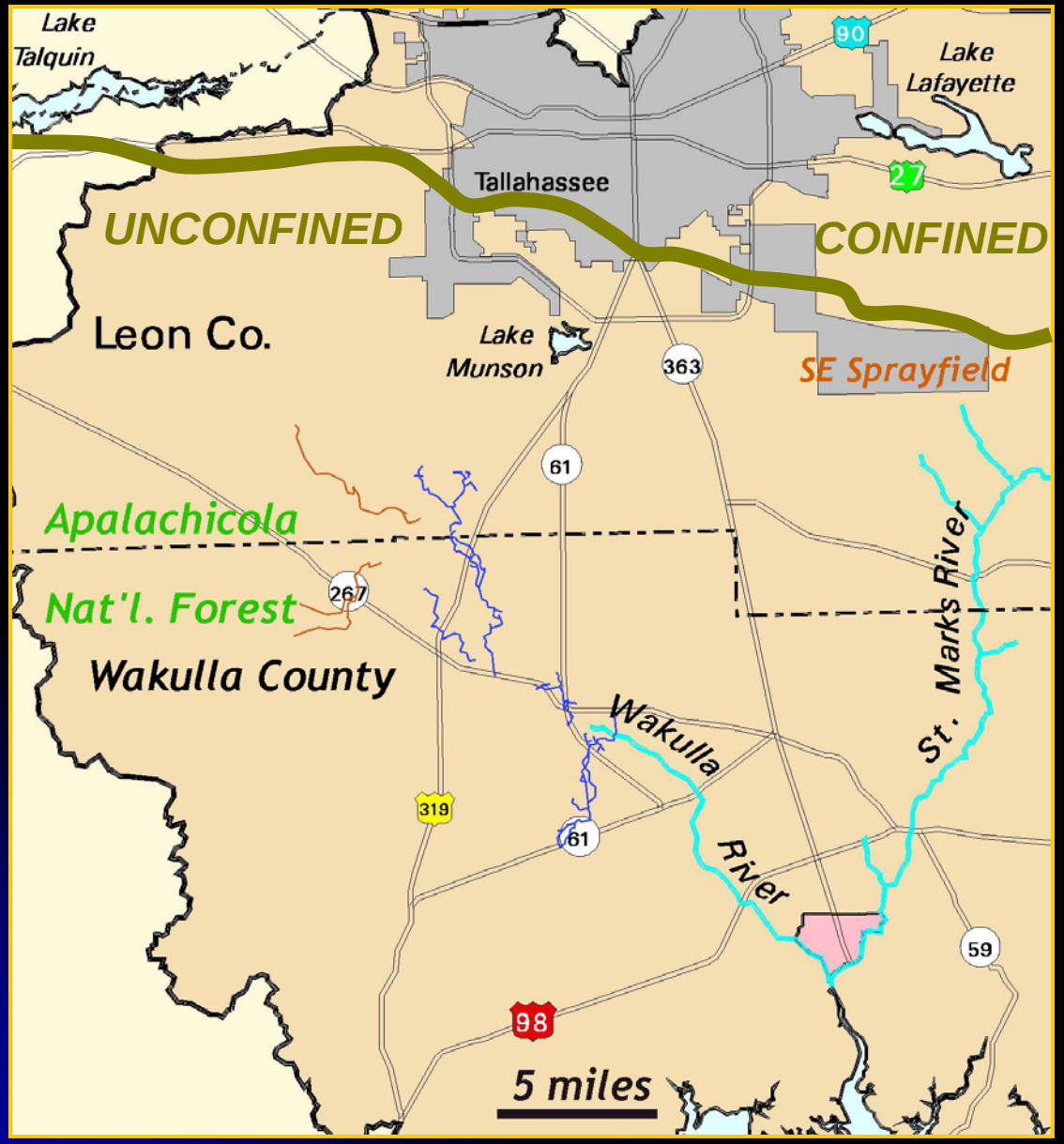
Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Presentation Overview

1. Problem Setting and Key Features
2. Research Objectives
3. Scientific Approach
4. Results
5. Application of Results
6. Conclusions and Future Work

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

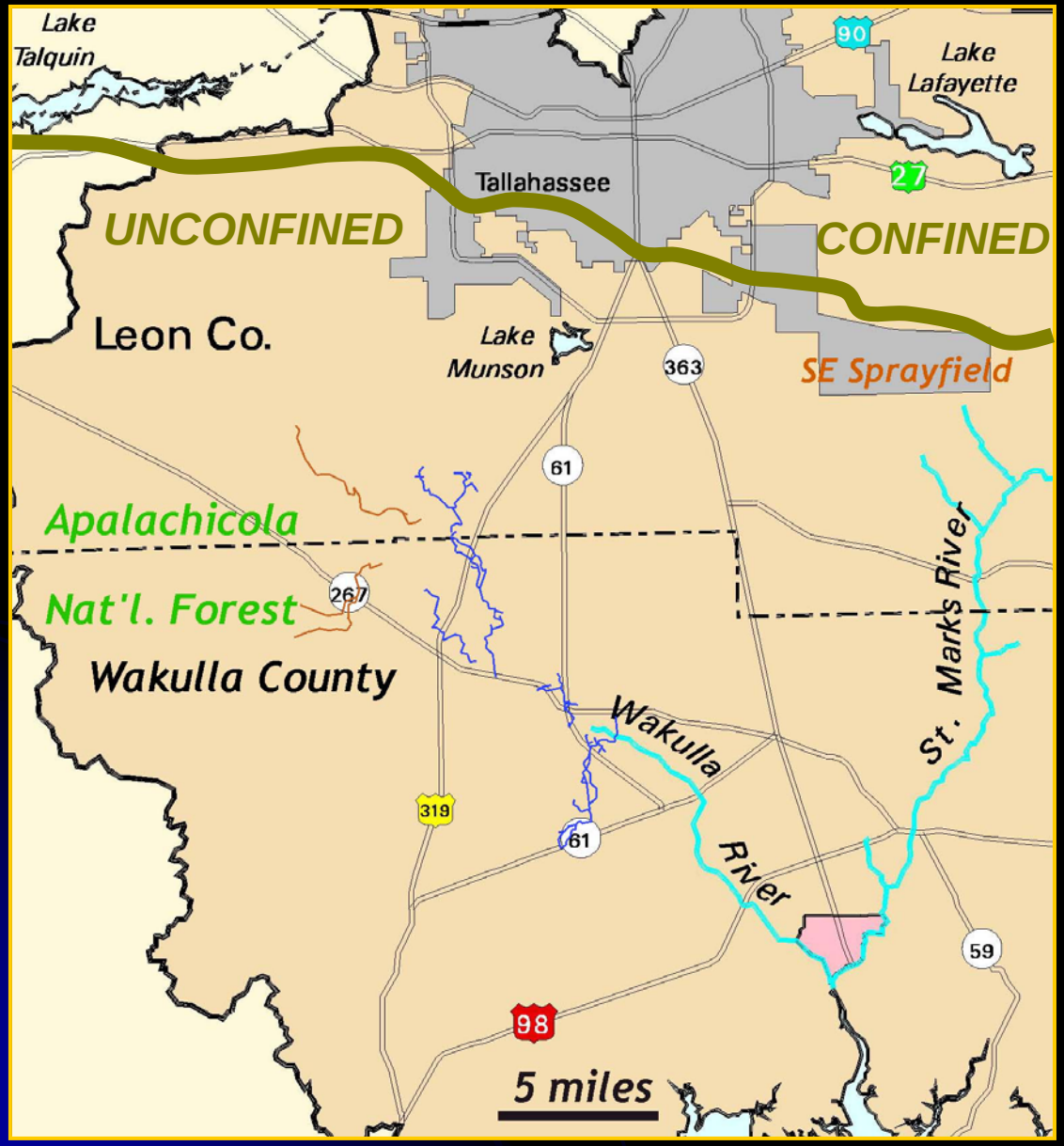
Problem Setting / Key Features (1)



- Primary Water Quality Degraders
  - Tallahassee
  - National Forest
  - Sprayfield
  - Septic Systems
- Boundaries
  - Cody Scarp
  - Leon-Wakulla Co.

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

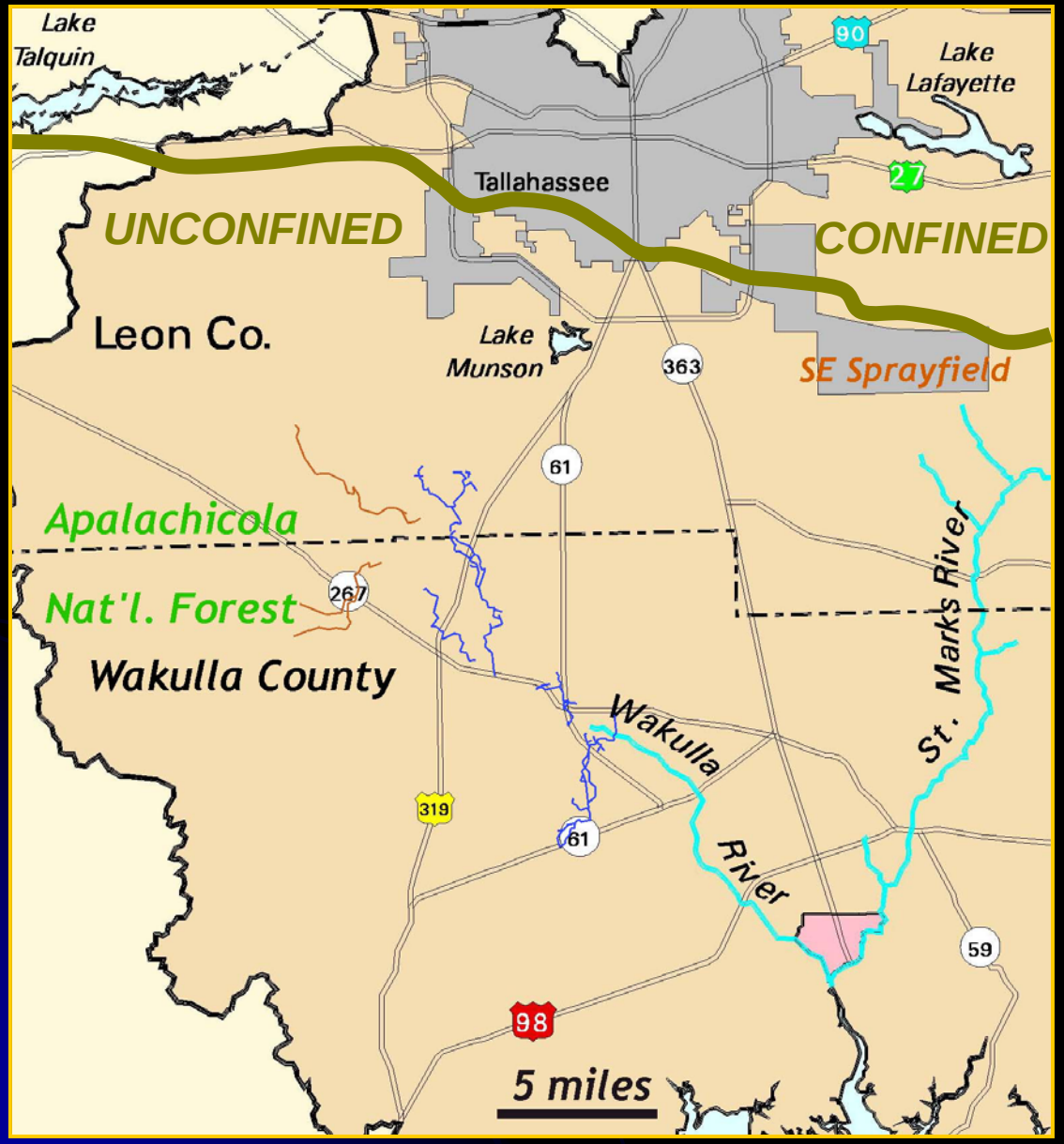
Problem Setting / Key Features (2)



- Key Surface Water Features
  - Lake Munson and the Slough
  - Drainages in National Forest (Black Creek, Fisher Creek, etc.)
  - Wakulla River
  - St. Mark's River

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Problem Setting / Key Features (3)



- Key Water Exchange and Subsurface Features
  - Leon Sinks Cave
  - Wakulla Cave and Spring
  - Various Sinkholes
  - Other Springs

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

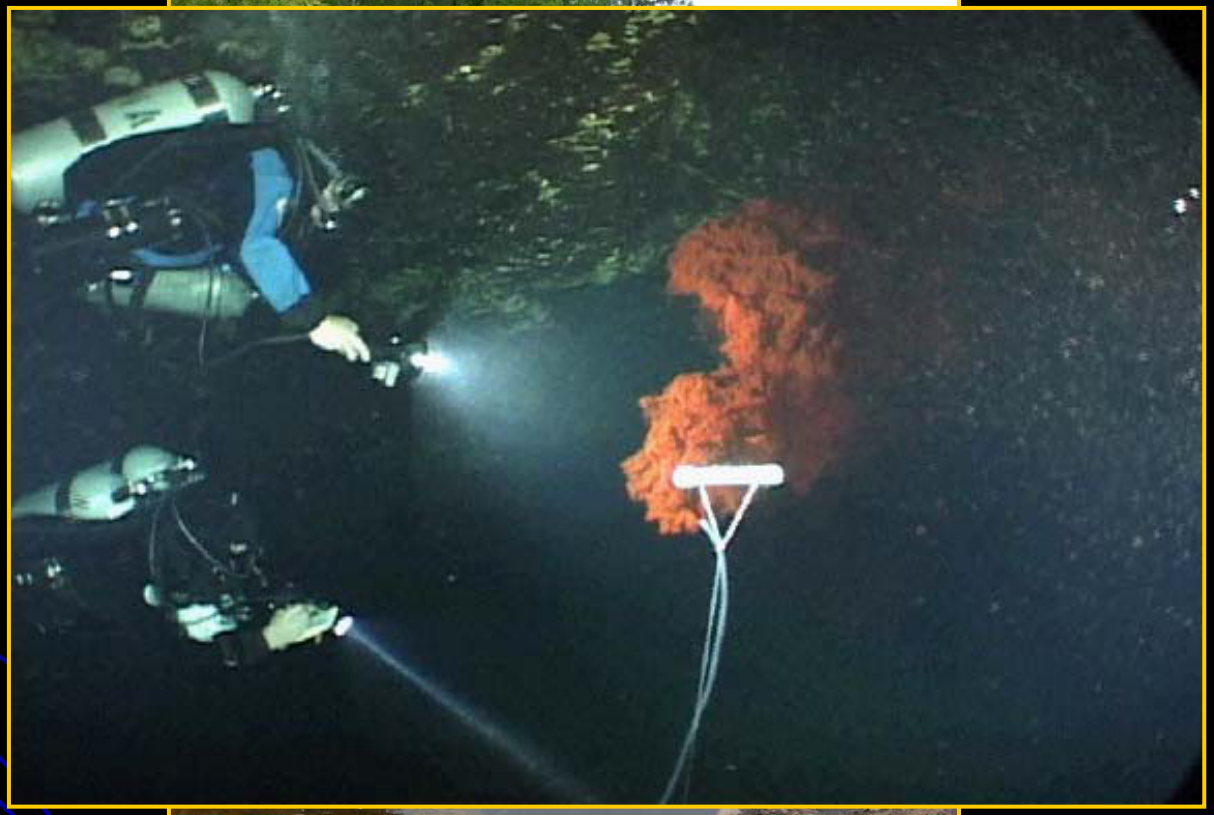
Research Objectives

- Quantify the Behavior of the Karst Flow System
  - Tracing
  - Metering
  - Modeling
    - Delineate Springsheds
    - Include Karst Features
- Improve on Existing Modeling Approaches
- Improve on Travel Time and Age Estimates
- Develop a Water Resource Planning Model
  - Water Resource Protection
  - Spring Protection

Scientific Approach

- Quantitative dye tracing
  - Inject single pulse of fluorescent dye
    - Directly into cave system at sinkholes
    - Sinking streams
  - Sampling
    - Auto-samplers drawing directly from downstream points in cave system via sinkholes and at spring
    - Dye detected below visible limits (ppb to ppt)
- Meters (covered earlier by Dr. DeHan)
  - Installed directly into caves
  - Connected via cables through wells
  - Measuring temperature, conductivity, direction, velocity
- Flow modeling including karst features
  - FEFLOW – discrete feature finite element model (dual porosity)
  - KARSTMOD – new model in development with D. Loper (FSU)

Quantitative Dye Tracing - Injection

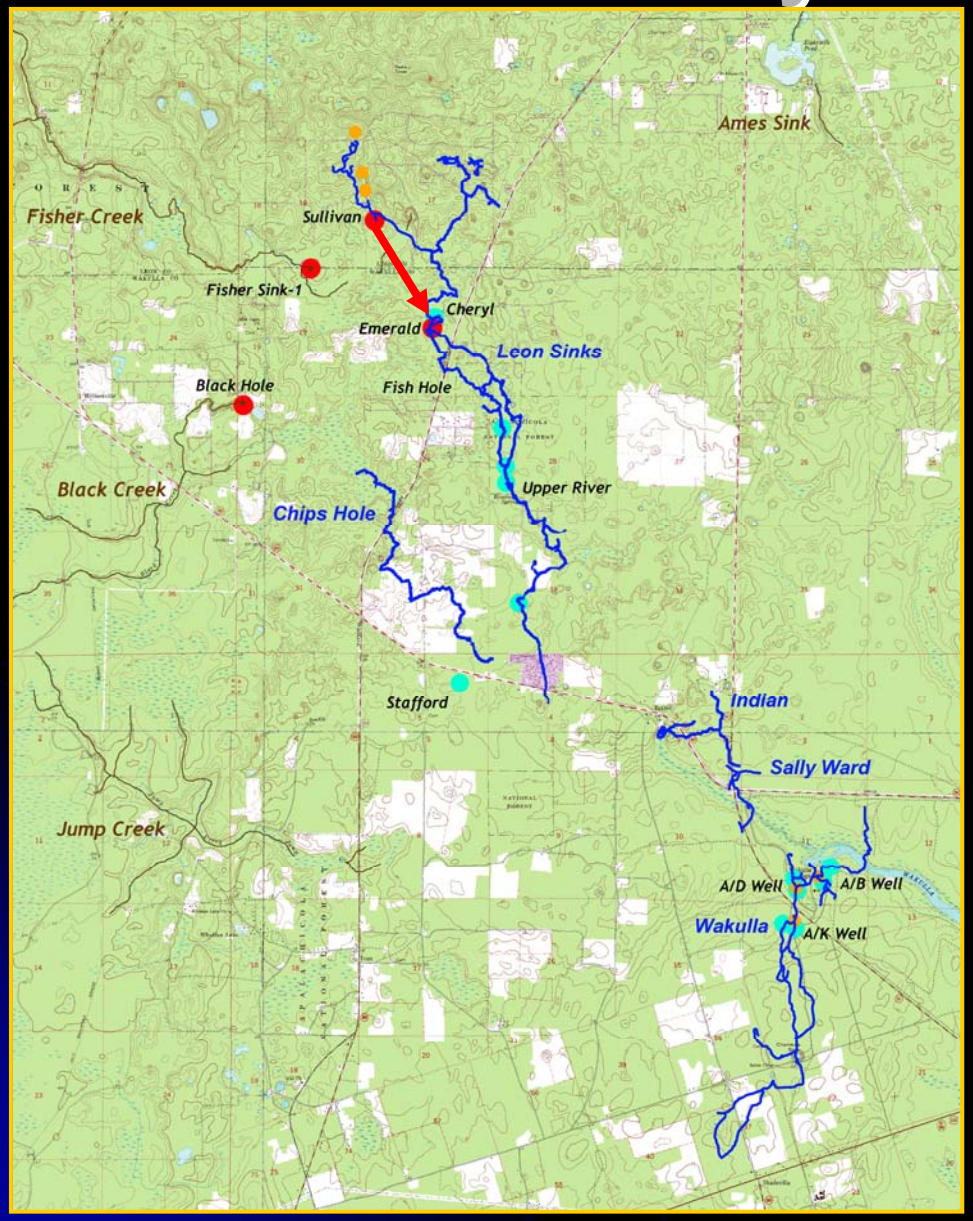


Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Quantitative Dye Tracing - Sampling

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

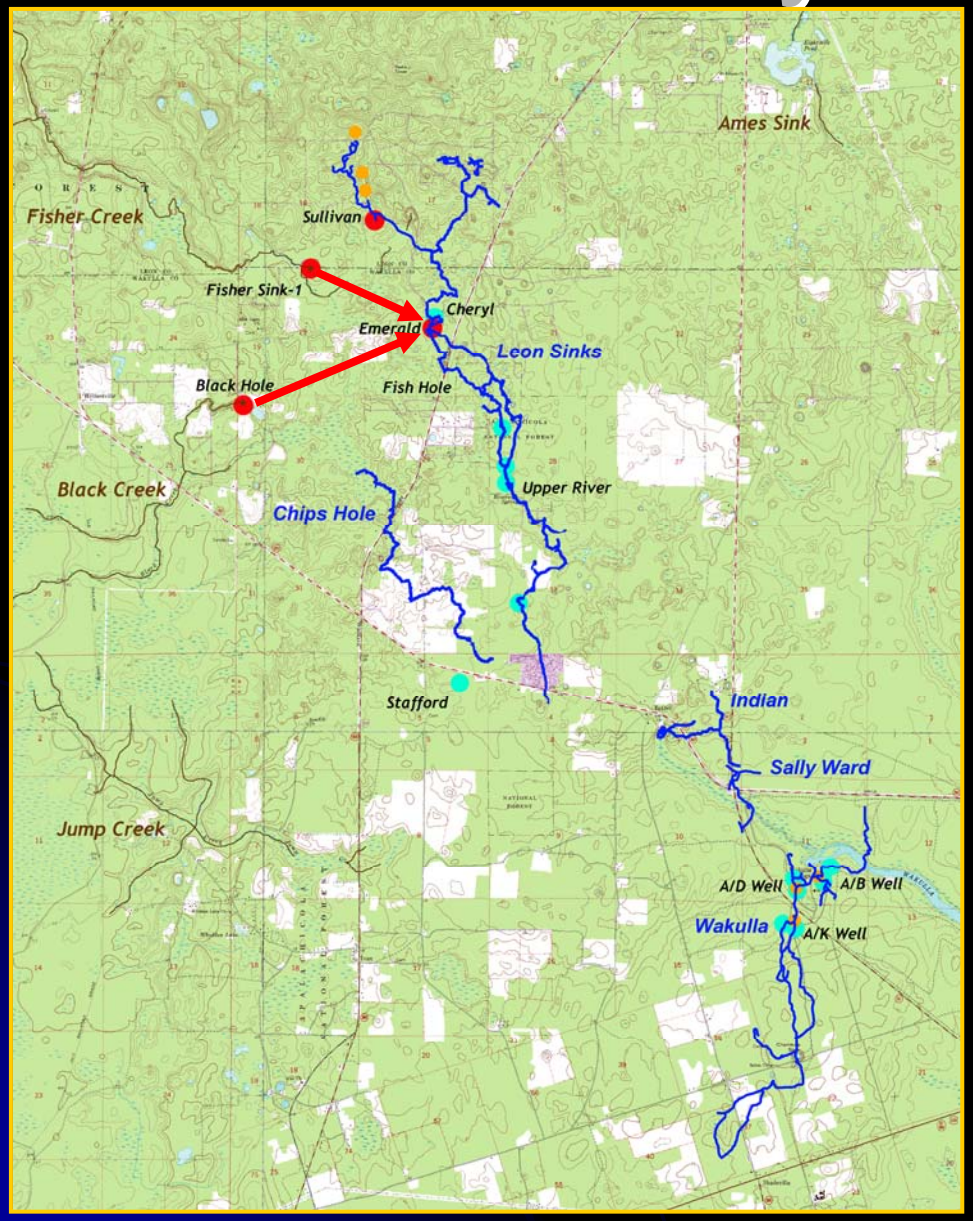
Quantitative Dye Tracing - Results



- Analysis of breakthrough data using QTracer (Malcolm Field, EPA)
- Sullivan to Cheryl
  - ~2500 m
  - 750 g Phloxine dye
  - Travel time = 23 hours
  - v = 1.8 Km/d
  - D_L = 12.3 m
  - Re = 184,874

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

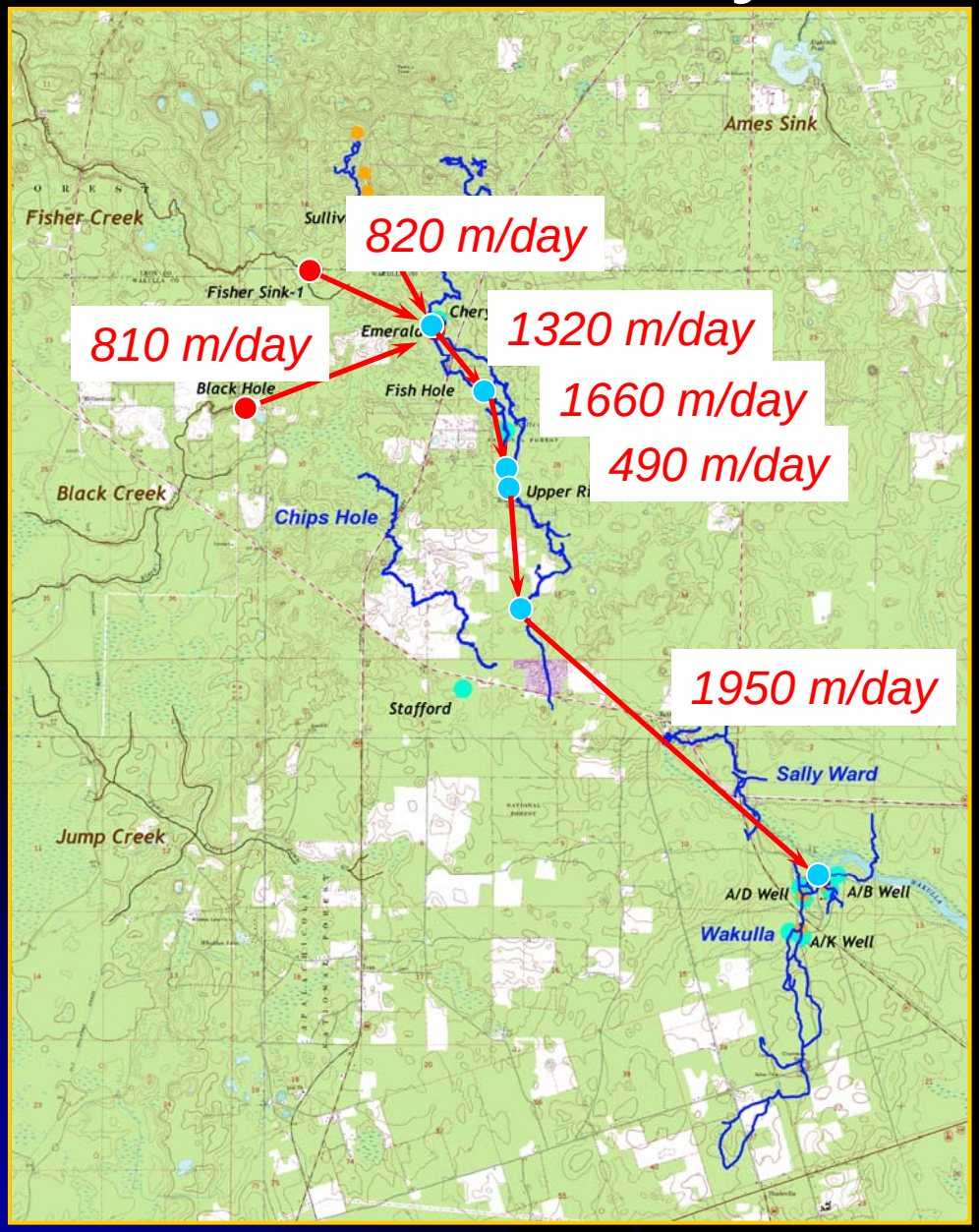
Quantitative Dye Tracing - Results



- Fisher to Emerald
  - ~1935 m
  - 2 Kg of Uranine dye
  - Travel time = 57 hours
  - $v \approx 820$ m/d
- Black Creek to Wakulla
  - ~15 Km
  - 3 Kg Phloxine dye
  - Travel time = 10 d
  - $v \approx 1500$ m/d

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

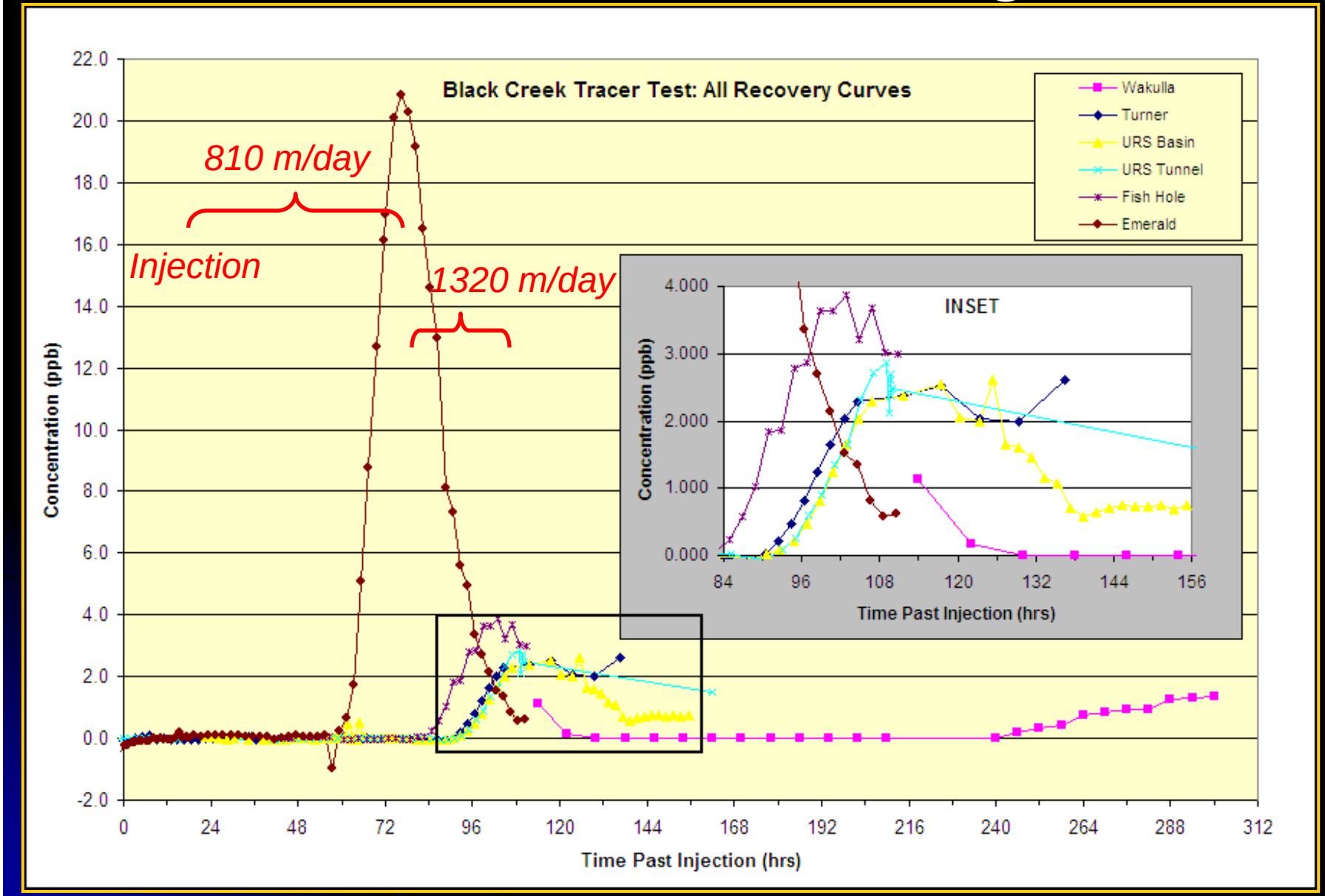
Quantitative Dye Tracing – Velocity



- Break through curves measured at each sampling station
- Velocities between stations calculated from peak-peak travel times
- To-Conduit Velocities: ~ 800 m/d
- Through-Conduit Vel:
  - 490 – 1950 m/d
  - affected by conduit diameter

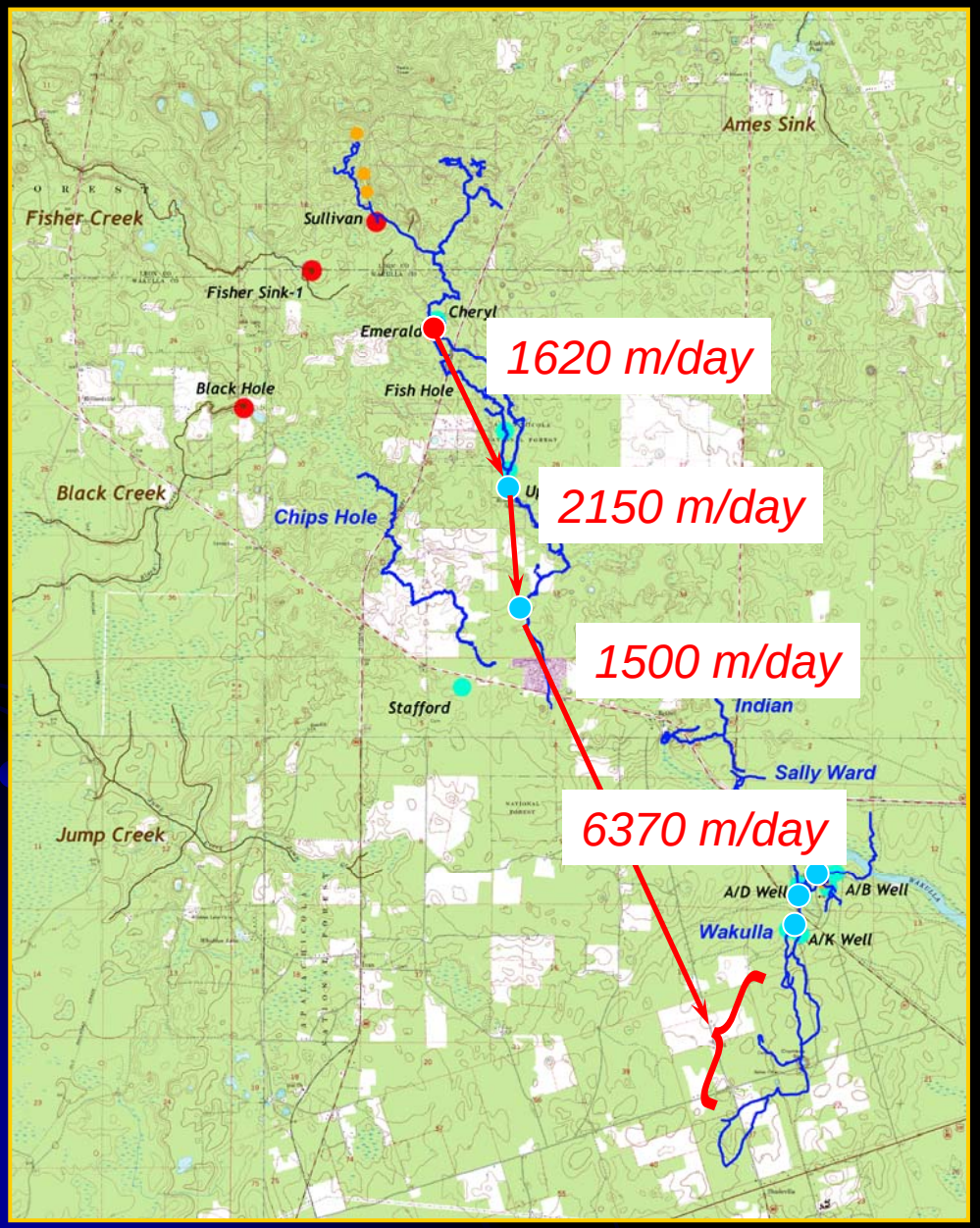
Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Black Creek – Breakthrough Curves



Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

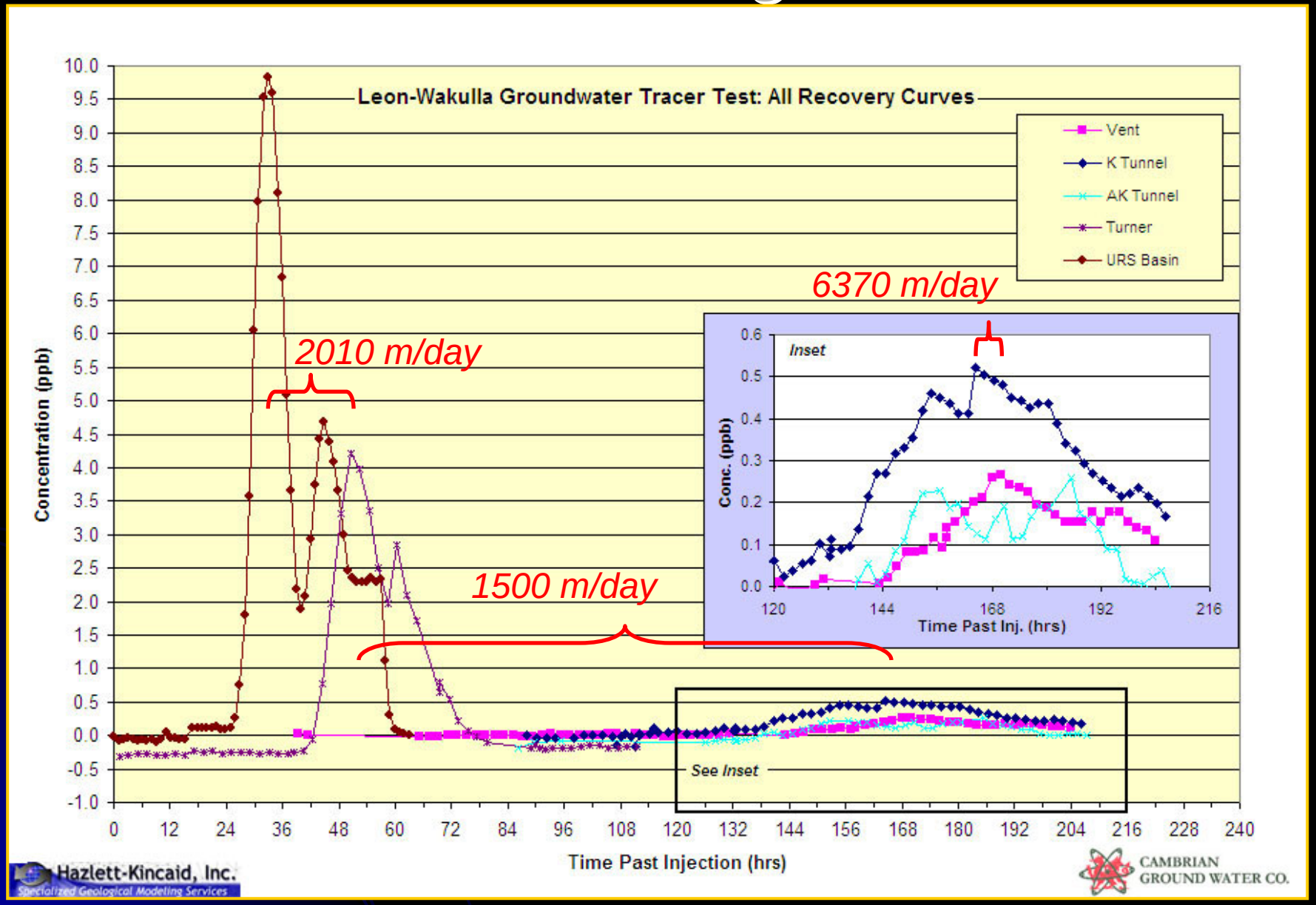
Quantitative Dye Tracing - Results



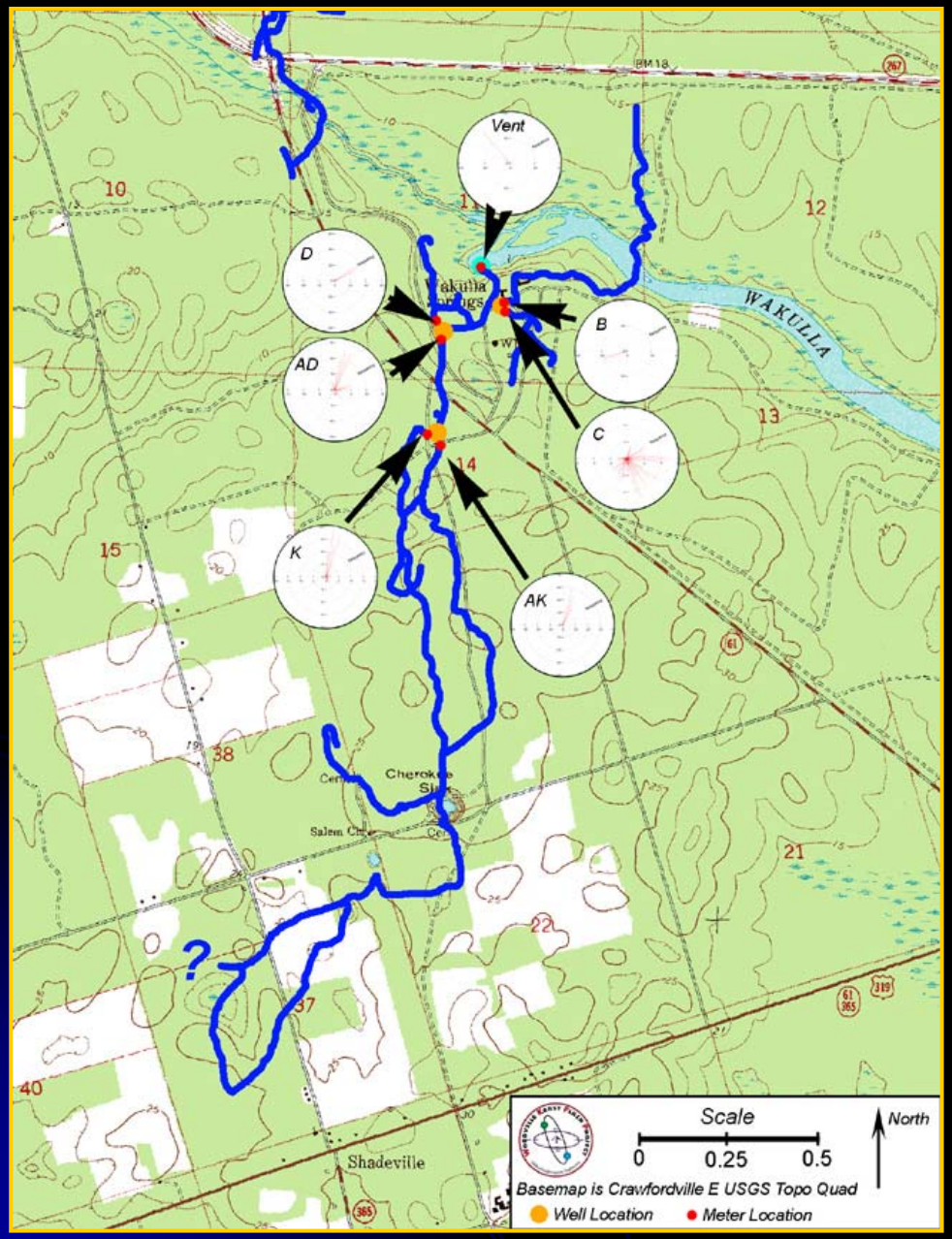
- Emerald to Wakulla
  - ~12.45 Km
  - 3 Kg of Uranine dye
  - Travel time = 170 hours
  - $v_{min} \approx 1500$ m/d
  - $v_{max} \approx 6370$ m/d
  - $v \approx 2300$ m/d
  - $D_L = 74.5$ m
  - Re = 762,000

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

All Breakthrough Curves



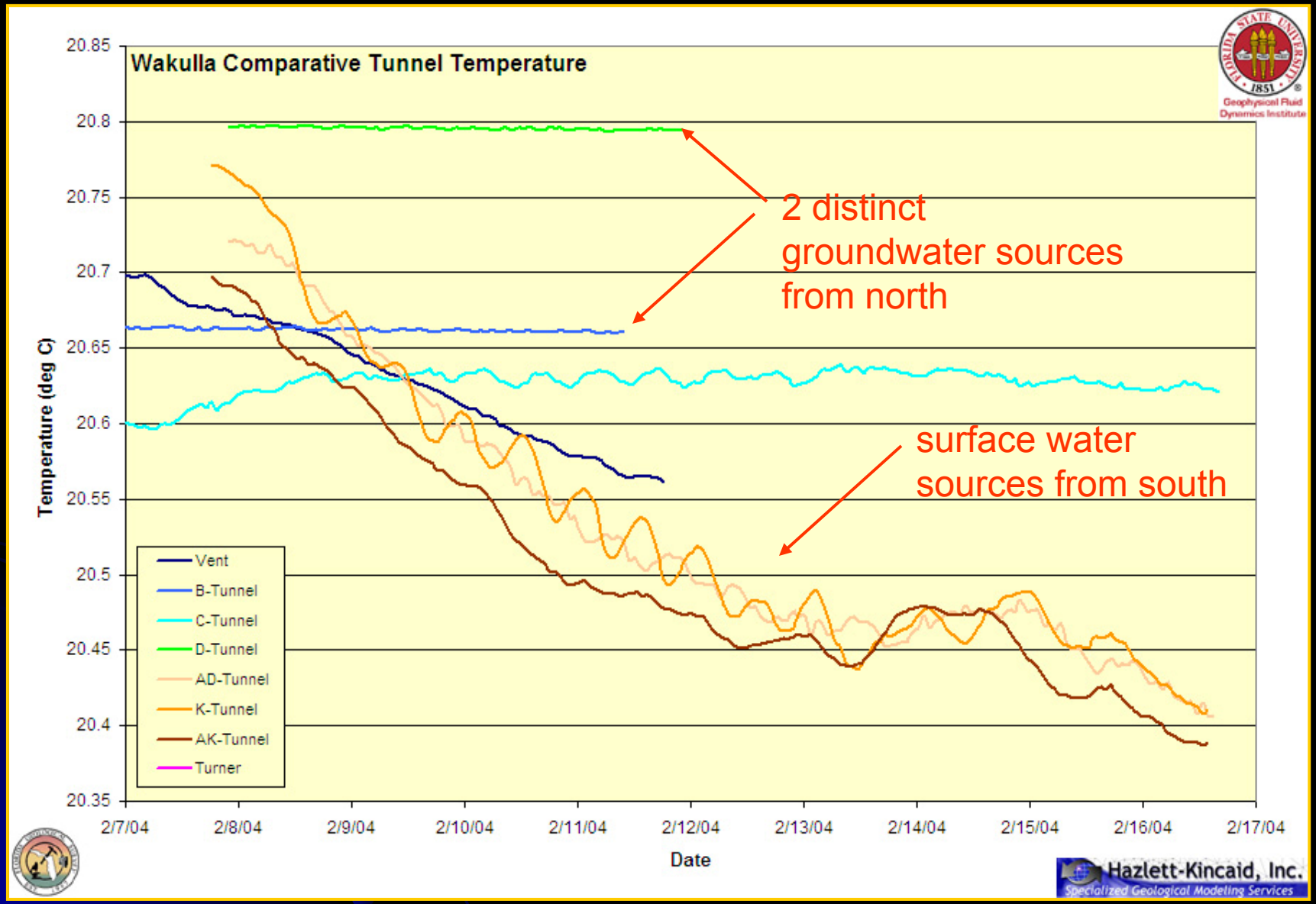
Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services



Meter Locations

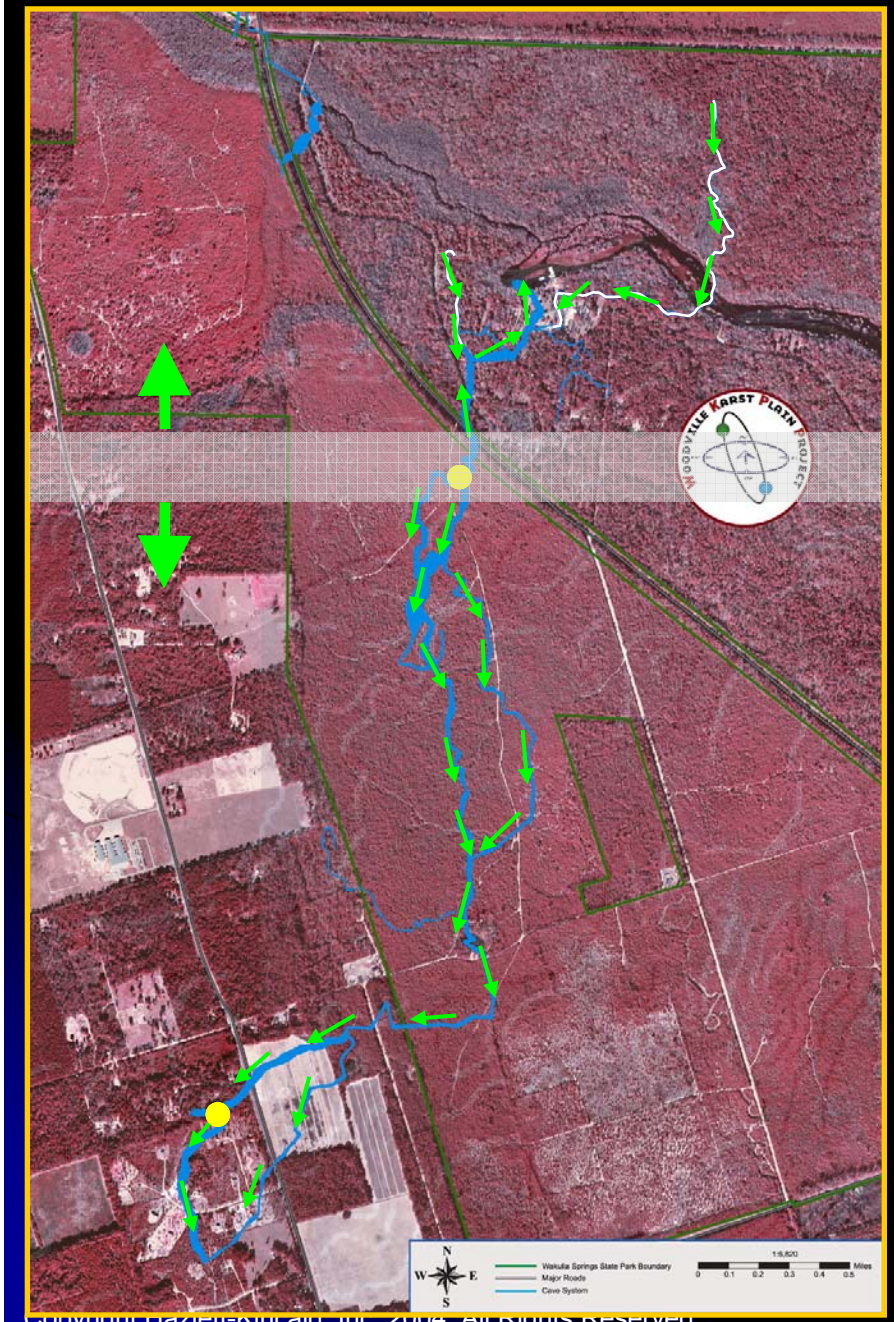
Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Comparison of Dye Tracing Data to Other Data



Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Wakulla Cave Flow Directions

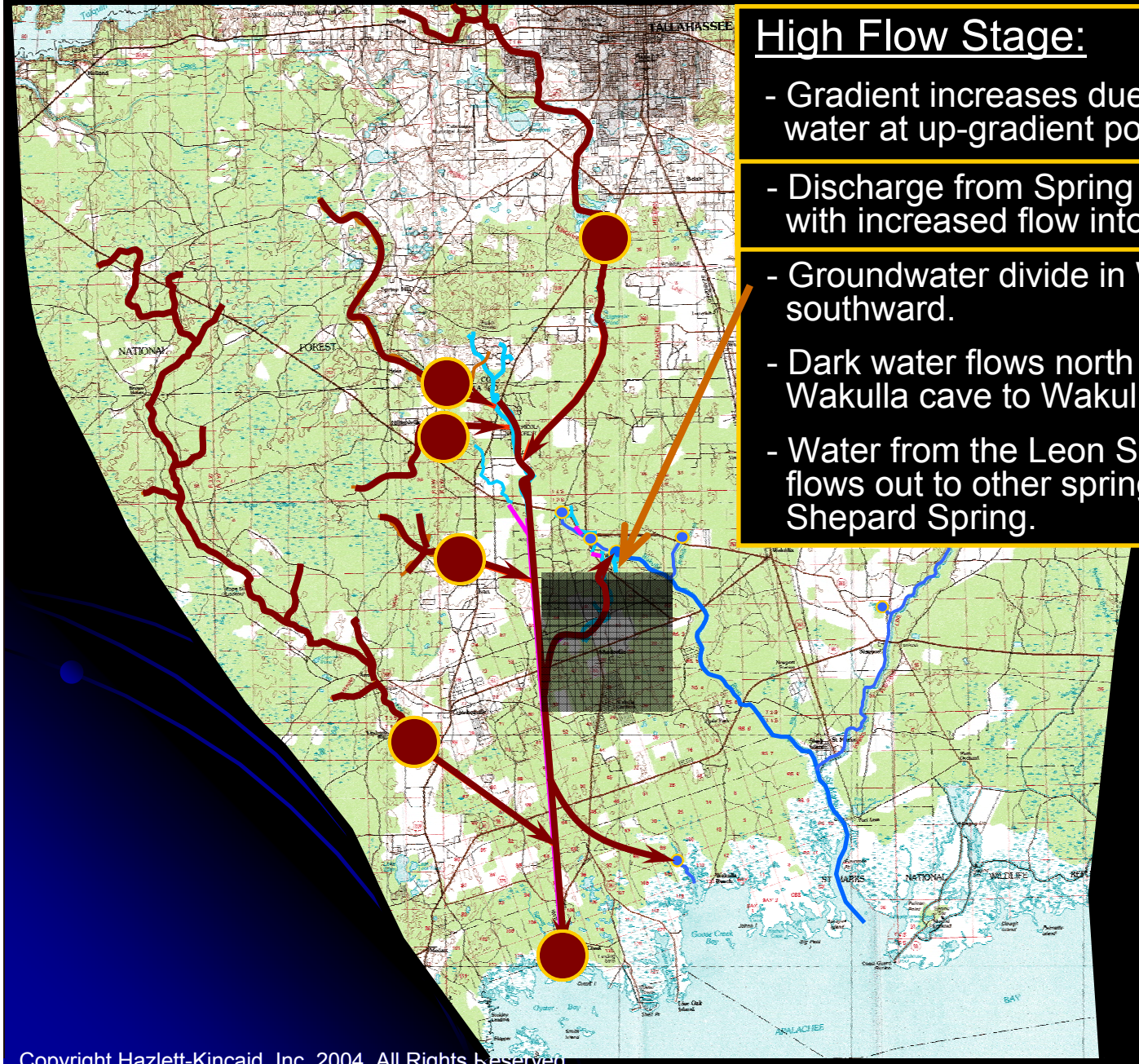


P-Tunnel

- Current end of exploration approximately 4 miles south of the cave entrance at Wakulla spring.
- Cave turns to west/southwest and continues at a lead to the west approximately half way down the tunnel.
- Potentially connects to Leon Sinks cave system.
- Conduit diameter averages > 100 feet.

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Where does the dark water come from?



High Flow Stage:

- Gradient increases due to mounding of surface water at up-gradient points of recharge.

- Discharge from Spring Creek cannot keep pace with increased flow into conduit system.

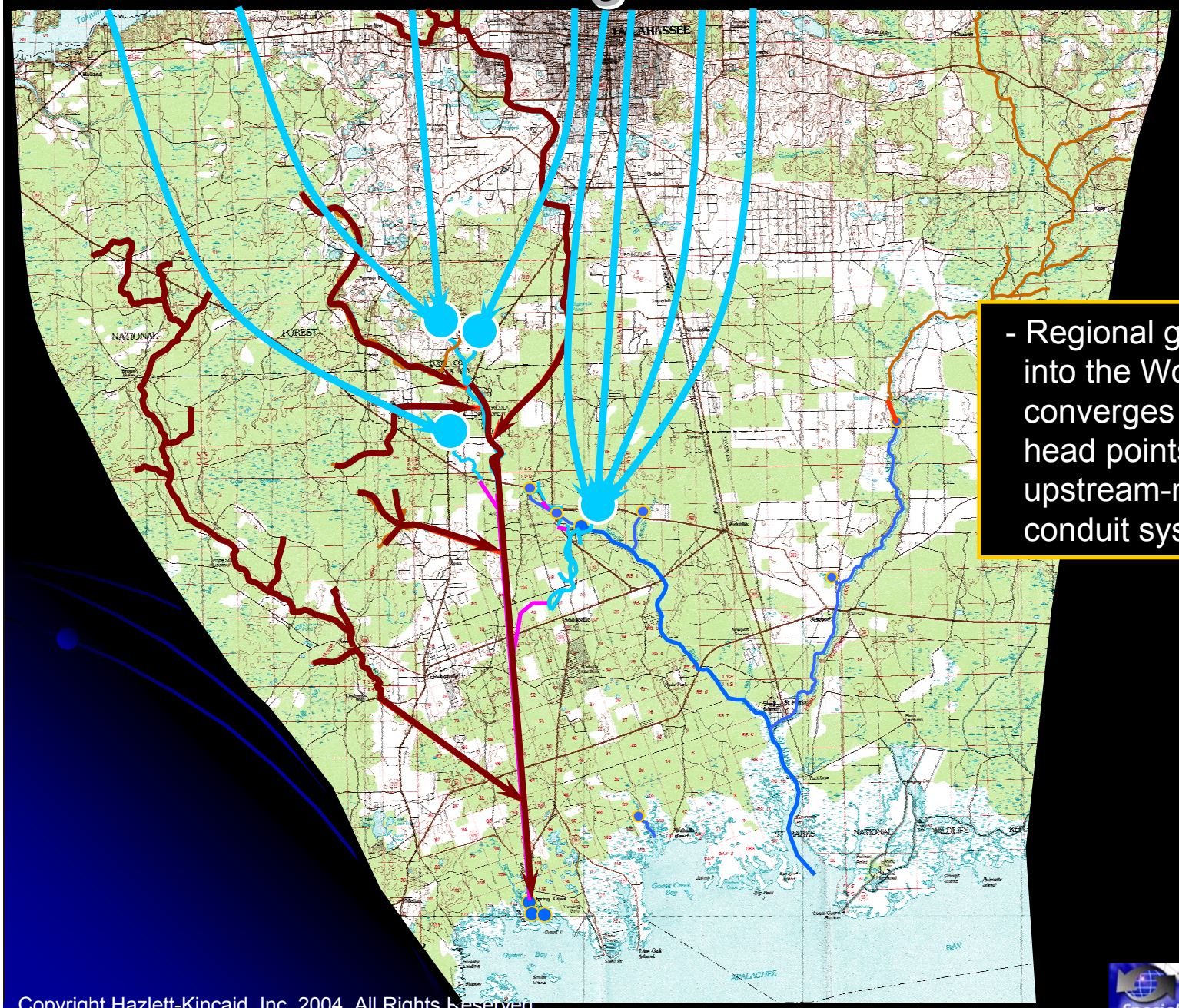
- Groundwater divide in Wakulla migrates southward.

- Dark water flows north in the large tunnels of Wakulla cave to Wakulla Spring.

- Water from the Leon Sinks cave system also flows out to other springs along the coast like Shepard Spring.

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

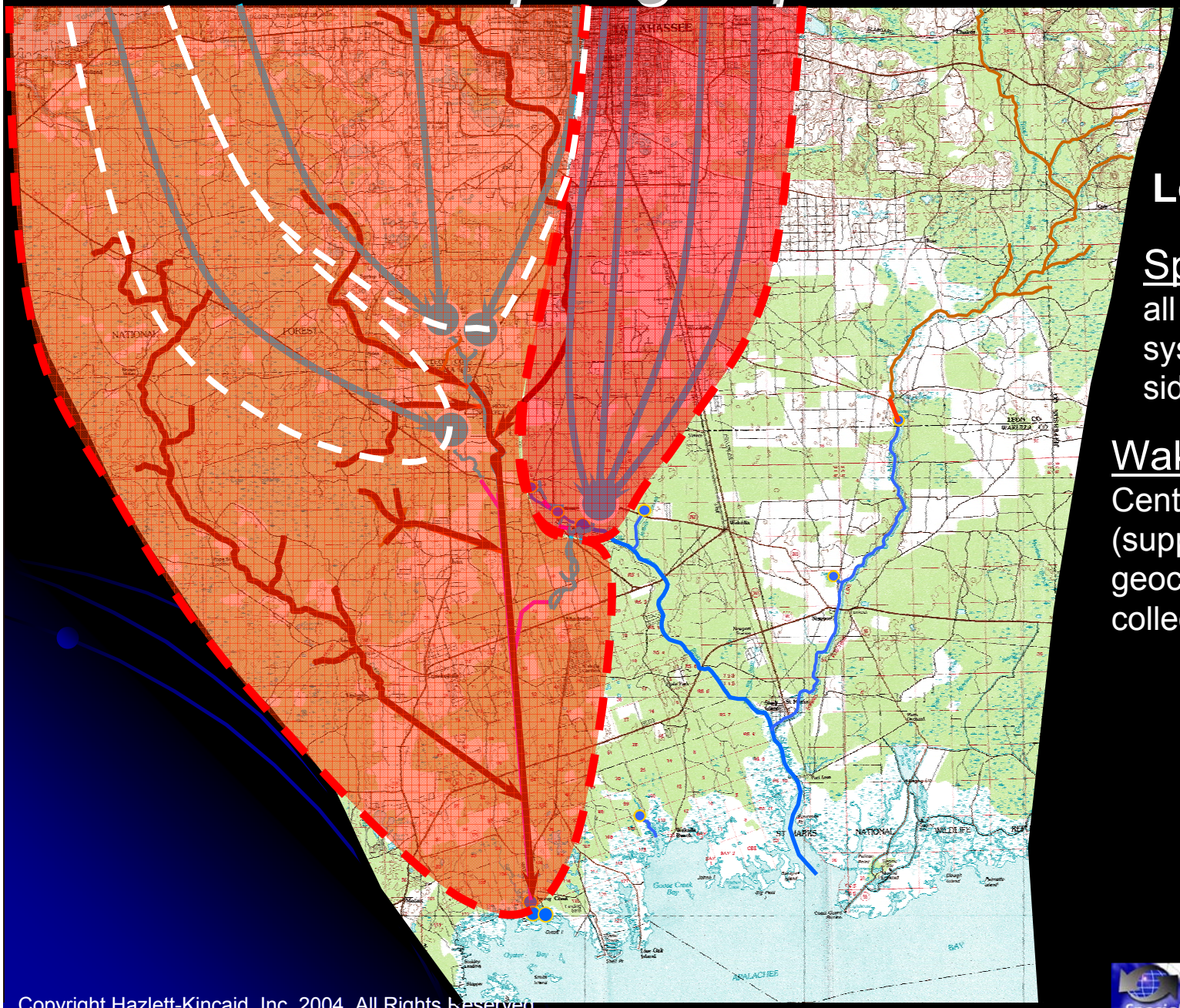
Where does the groundwater come from?



- Regional groundwater flow into the Woodville Karst Plain converges on the local low head points, which are the upstream-most points of the conduit systems.

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Probable spring capture zones ???



Low Flow Stage

Spring Creek

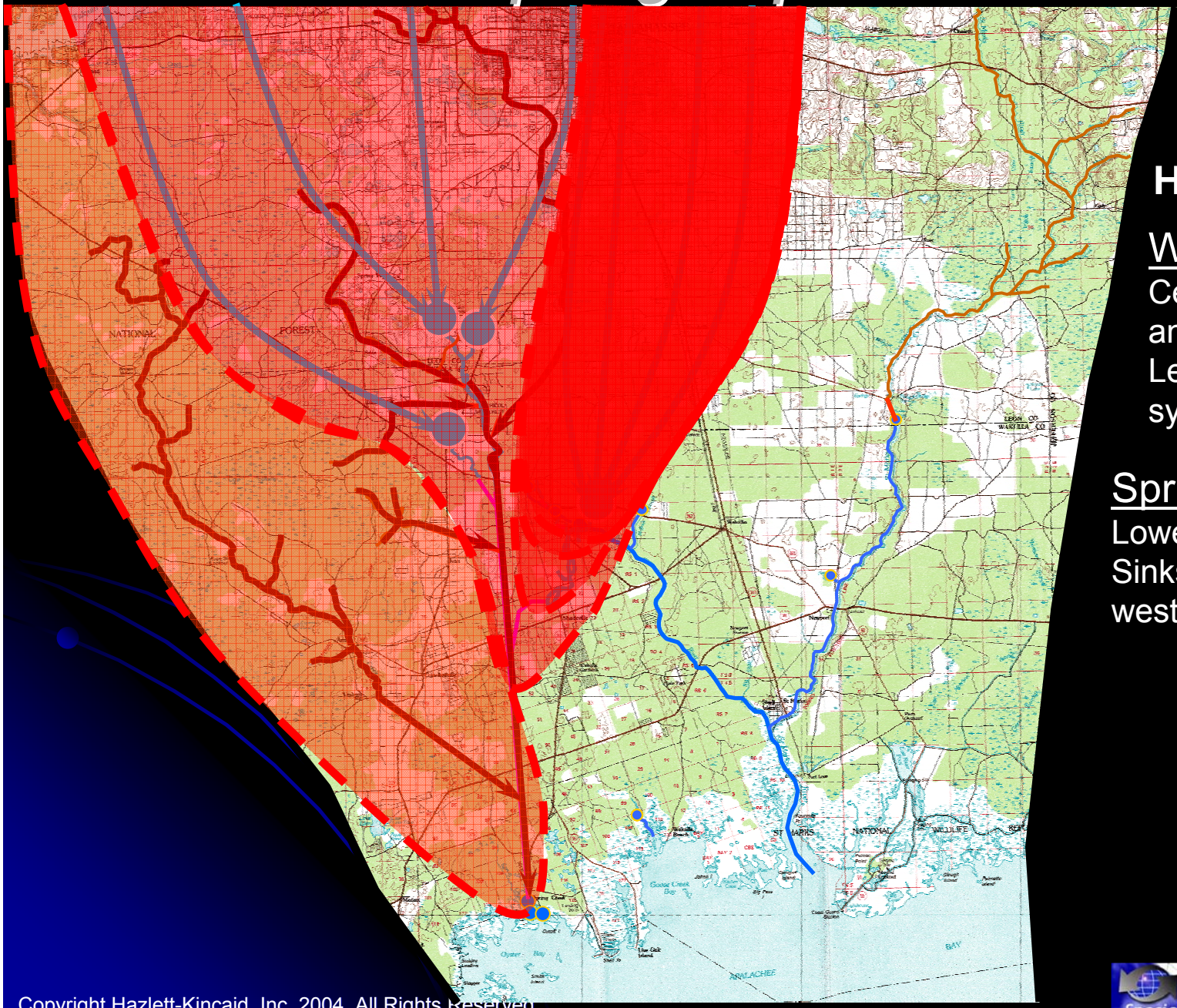
all of Leon Sinks cave system and western side of basin

Wakulla

Central part of basin (supported by geochemical data collected by NFWMD)

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Probable spring capture zones ???



High Flow Stage

Wakulla

Central part of basin and upper part of Leon Sinks cave system

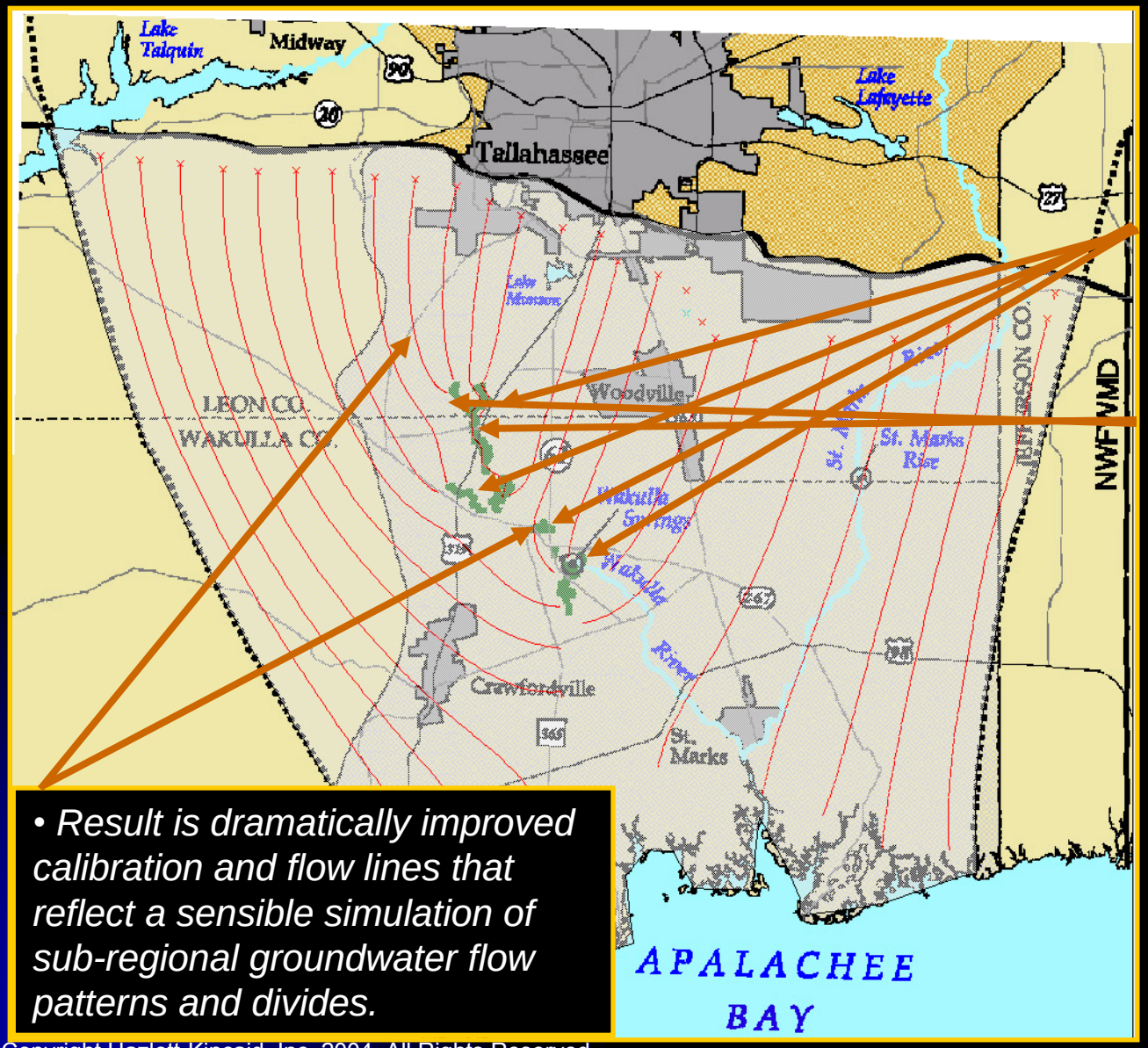
Spring Creek

Lower part of Leon Sinks cave system and western side of basin

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Application of Results

- Modeling is possible and practical if it embraces karst complexity



• *Result is dramatically improved calibration and flow lines that reflect a sensible simulation of sub-regional groundwater flow patterns and divides.*

Finite-Element Groundwater Model of the Woodville Karst Plain

Developed by Hazlett-Kincaid, Inc.

- *All mapped caves are incorporated into the model framework (easier in FE framework).*
- *Tracer test data documenting groundwater velocities along mapped and un-mapped preferential pathways are used in calibration.*
- *Model is calibrated and optimized to heads and spring discharges.*

Hazlett-Kincaid, Inc.
Specialized Geological Modeling Services

Conclusions and Future Work (1)

- Leon Sinks connects to Wakulla from south of Wakulla Spring
- Dark water at Wakulla Spring comes from Leon Sinks drainages
- Dye tracing results are confirmed by the meter data (example is temperature)
- Water budget for WKP is dominated by caves
  - Most of water goes to Wakulla Spring and Spring Creek
  - All major surface drainages on WKP go underground
- The WKP is likely the most tractable karst basin in Florida
  - Small # of large springs dominate discharge
  - Small # of small springs
  - Dendritic contributory pattern of saturated caves
- Flow through conduits is non-Darcian and highly turbulent
- Porous media flow models do not apply
- Including caves in models improves water residence time estimates by 2 to 3 orders of magnitude
- Traditional age dating methods provide no insight into the nature of the flow system, as proven by tracing results
- Water Budget = Bulk of Flow to 2 Big Springs + 10^2 less to small springs + 10^5 less diffuse discharge

Conclusions and Future Work (2)

- Wakulla drawing water from ~5.5 Km south of spring
- How do resource management decisions change per our new results?
  - Improved residence time estimates changes “ball game” dramatically
  - Huge implications for planners and contamination issues
- Confirm remaining major cave connections
- Model rainfall-discharge relationships
- Model basinal flow system with primary karst features
  - Land planning tool
  - Resource protection tool
- Establish HO